MOTION AND DECAY OF NEAR-WALL LIQUID FILM AT ITS OUTFLOW WITH COCURRENT GAS FLOW FROM THE CYLINDRICAL CHANNEL INTO VACUUM

V.G. Prikhodko, A.F. Serov, A.D. Nazarov, and I.V. Yarygin
S.S. Kutateladze Institute of Thermophysics SB RAS,
630090 Novosibirsk, Russia

Introduction

The problem of a liquid flow expelled into vacuum is interesting both in theoretical and practical aspects. In the fundamental framework, research of physical processes and phenomenon accompanying the outflow of a fluid into vacuum is of great importance: an instantaneous boiling, breaking into drops, phase transitions at the droplet surface and inside, the interaction of drops with supersonic flow, etc. As for practical applications the outflow of a fluid into vacuum is of interest, in particular, for space engineering from the point of view of contamination of a space vehicle surface during operation of its venting devices, operation and orientation thrusters, systems of refueling by propellants, etc [1].

Despite of certain interest to the given problem, the number of articles devoted to outflow of fluids and gas-liquid mixtures into vacuum is extremely limited. They deal mainly with water election into vacuum. At the same time there are a lot of items concerning research of pure gravity motion of liquid films [2]. As for film motion with cocurrent flow of gas, the number of such studies is rather great, however they are fulfilled mainly at pressures close to atmospheric and concerning low-level (subsonic) speeds of a gas flow [3].

One of features of the considered problem consists in the fact that most of liquids at the outflow into vacuum become overheated even at room temperature, that results in explosive rupture of a film with formation of a vapor phase and drops of a miscellaneous size. Other feature of the problem lies in strong effect of cocurrent gas flow on motion of the film inside the channel and at the outflow into vacuum.

Experimental setup and measuring technique

The outflow of a wall film of ethanol with a cocurrent flow of air from a tube with the diameter of $d = 10$ mm and relative length of $l/d = 2$ into ambient space was experimentally researched in our work, the initial pressure in space was about 10^{-1} Pa. At the same time some of experiments were conducted at more high pressure in ambient space, up to atmospheric. The researches were performed on the large-scale vacuum setup VIKING [4]. Sufficiently big volume of the vacuum chamber of setup VIKING (about 150 m^3) provided broad possibilities for operation in pulse modes.

The scheme of a working section is shown in Fig. 1. The tube *4* was installed vertically downwards inside the vacuum chamber. On an inlet of the tube there was a broadening (up to diameter of 22 mm), playing a role of a prechamber. An air was fed into prechamber, the fluid, an ethanol, was fed along a wall through an annular gap. The mass consumption of gas and fluid could be set separately from each other and vary within wide range of limits. The researches were conducted in a pulse mode, the time of ejection of the liquid film and gas was several seconds. In experiments the thickness of the liquid film near the exit section of the channel was measured, and the videoshooting of the process of the outflow of the film with different time resolution was made also.

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Abstract

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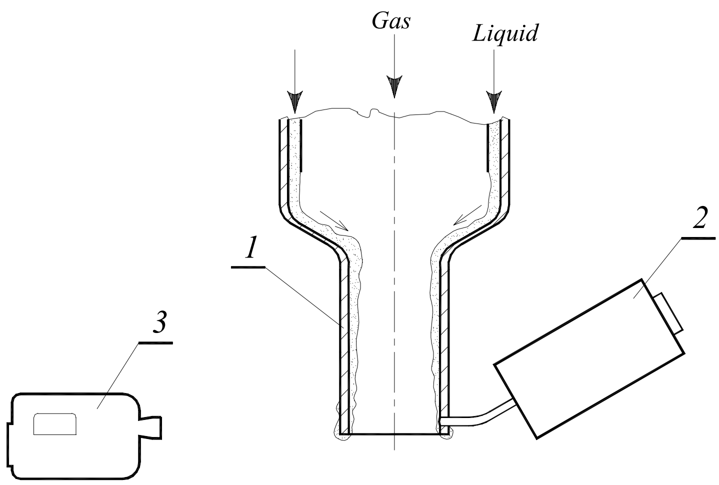

Fig. 1. *1* – tube, *2* – probe of film thickness, *3* – videocamcorder.

The measurements of the film thickness were carried out with the help of specially designed coaxial probe of a capacity type. Detail description of a principle and technique of measurement can be found in [5]. In the given work the probe with an external diameter of 2 mm was used. The probe was fixed flush with an internal surface of the tube and installed apart 2 mm from outlet of the tube (Fig. 1).

The hardware of a capacity meter of local thickness of a film consists of a primary converter and multichannel electronic block connected to IBM PC through LPT-port. The meter is controlled by the special program. Functions of the program: definition of parameters of measurement, primary processing and picture representation of the experimental data. For definition of local thickness of a film the through frequency characteristic of a capacity meter is taken into account. For this purpose the spectral distribution of the wave film is being determined, the frequency correction is being brought in and the true form and amplitude of waves are being determined by inverse Fourier transformation.

In a part of experiments simultaneously with measurements of thickness of a film the videoshooting of the process of the ejection with the shutter period of up to 1/8000 sec was maid, that in conditions of the conducted experiments provided obtaining practically "instantaneous" flow patterns. The pictures were recorded from the outside of the vacuum chamber through an illuminator with the diameter of 400 mm from distance of about 1.7 m to the jet axis. To make pictures brighter the liquid jet was illuminated by an external light source with the power of 2,2 kW.

Results of experiments and their analysis

Measurement of thickness of the film at exit section of the tube. Typical observed data of liquid film thickness near to exit section of the tube are presented in Fig. 2 for two variants of the outflow the wall film into vacuum - without cocurrent flow of air (without gas, Fig.2,a) and at presence of a cocurrent flow of air (with gas, Fig.2,b). The conditions of organization of the wall film of ethanol (total rate of liquid G_{liq} = 2,5 *g* and time of feed of 5 sec) were identical in both cases. It is possible to see that the presented data on thickness of the film differ both on character of behavior, and on the value. Let's consider these results in details. In Fig. 2,a we can

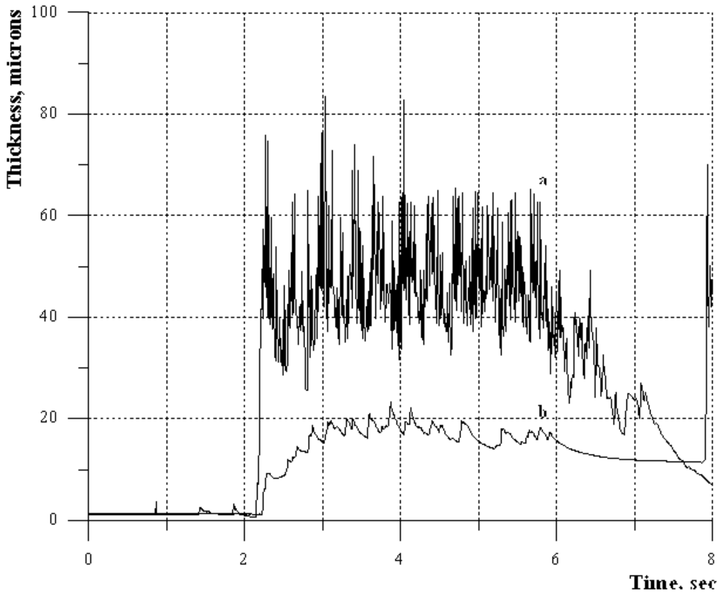

Fig. 2. Thickness of liquid film. *a* – without co-current gas flow, *b* – with gas flow.

see, that for this case (film without cocurrent flow) the average thickness of the film is approximately 50 microns, and the strong oscillations of a signal or, that same, thickness of a film are watched. The moment of incoming of the film on the sensor (approximately on 2 sec) and life time of a film (approximately 4 sec) are also seen enough clearly. As for the strong fluctuations of the signal, they seem to be caused by a volume boiling of liquid film at hit into vacuum. As it was mentioned above the initial pressure in the vacuum chamber (and accordingly in the tube) was about 10^{-1} Pa, while the saturated vapor pressure of ethanol is about $5{,}8\cdot10^{3}$ Pa at room temperature. Therefore at hit into the tube the fluid becomes overheated even at room temperature. Later some equilibrium value of pressure above the film may be set in. This pressure is higher than saturated vapor pressure, but lower than the pressure in vacuum chamber.

Presence of cocurrent flow essentially influences on parameters of the wall film (Fig. 2,b). In the first place, the strong decrease of pulsation of the film thickness is visible, that is caused by suppression of the process of a volume boiling - the air pressure in the cocurrent flow was than higher pressure of saturated vapor of ethanol. In the second place, the average thickness of the film also decreases, that is likely to be caused by acceleration of the film owing to appearance of shearing stress at a free boundary of the film. The estimated value of the Reynolds number for the film for this regime (Re_{liq} = 16) corresponds to the so-called wave mode [3]. Thus, the applied measuring technique of thickness of a film has appeared rather informative and has allowed receiving new results on motion of the wall film in the channel in different conditions of rarefaction. In further the attempts of usage of the given method for measurement of a spatial distribution of a droplet phase in gas-liquid stream formed while ejecting of the near wall liquid film accompanied by a gas stream into vacuum were undertaken. These attempts have appeared rather reassuring, but the quantitative interpretation of observed data demands additional analysis.

Videoshooting of the process of liquid film outflow. An example of the “instantaneous” pattern of ejection of the wall film of ethanol into vacuum is given in Fig.3 (the shutter period

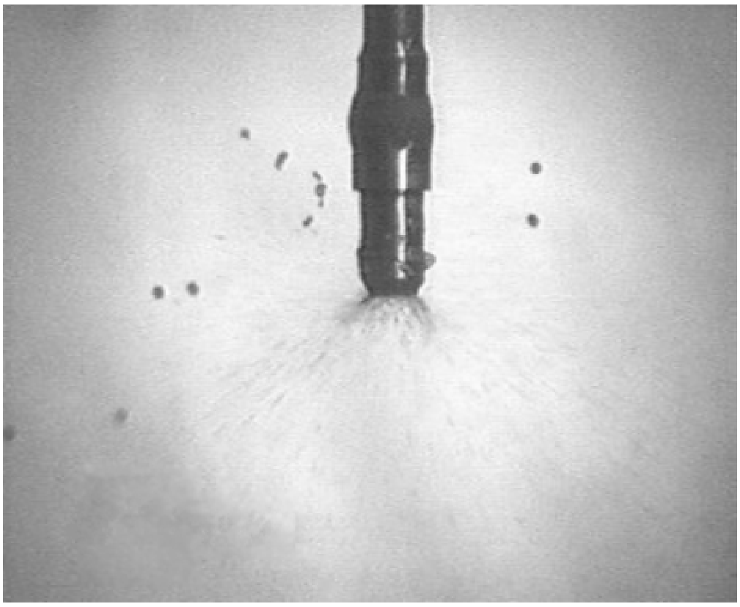

Fig. 3. “Instantaneous” pattern of ejection of the wall film of ethanol into vacuum.

of video camera was 1/8000 sec). It is possible to see a backflow of drops (at corners from an axis of a jet more than 90°). It was also revealed in experiments that wall liquid film, after it comes out from the tube, turns by 180° at the exit edge and starts moving upward on the external surface, even against gravitation. To understand this effect in detail, experiments were performed on liquid flow behavior with variation of the initial pressure in the ambient space (in the chamber) by 6 orders - from 10^{-1} up to 10^{5} Pa, with all remaining parameters of experiments saved constant. It was demonstrated that with increase in the absolute pressure in the ambient space the opening angle of the jet decreases, and at the pressure about 10 Pa (and higher) the liquid film ceases to move in the opposite direction. This is illustrated in Fig. 4, where the qualitative patterns of the outflow of the fluid into vacuum and into atmosphere are reproduced.

In our opinion one of the possible reasons of the liquid film backflow arising consists in origin of the Prandtl – Mayer flow at the outlet edge of the tube resulting in strong turning of the stream, up to appearance of backflow.

Therefore, we can assume that this return flow of vacuum-expelled gas or vapor makes wall liquid film move to the backward direction after passing the outlet edge of the tube. The

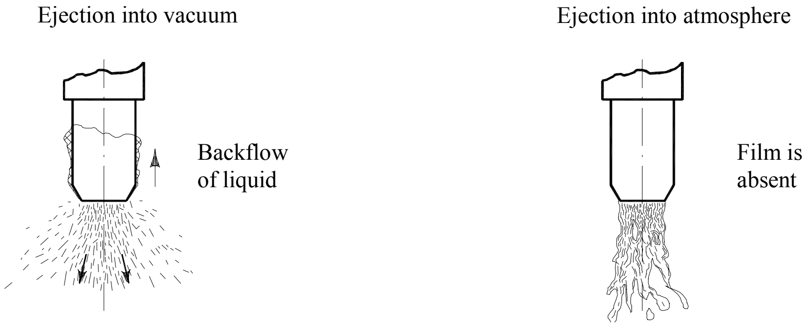

Fig.4. Ejection of the wall film into vacuum and atmosphere.

capillary forces of wetting and the expulsive force of liquid film moving on the inner surface also participate in this process. To understand this phenomenon more deeply, a wider experimental study and the theory development for the problem of liquid film flow into vacuum are required.

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